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Kootenai River White Sturgeon Spawning Migration Behavior and a Predictive Model

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Abstract.—Each autumn and spring, adult white sturgeon *Acipenser transmontanus* migrate from the lower Kootenai River and Kootenay Lake, British Columbia, to prespawn staging reaches in Idaho. In spring, they migrate further upriver to a spawning reach near Bonners Ferry, Idaho. We monitored movement and behavior of 49 reproductively mature white sturgeon with radio and sonic telemetry from 1991 through 1997. White sturgeon responded to mitigated flows from 1994 through 1997, migrating substantial distances to a spawning reach soon after the onset of local runoff and rising water temperatures. Males migrated at temperatures of 5.5–12.1°C, 2 weeks before spawning; females followed about a week later, at slightly warmer temperatures. Females stayed in the spawning reach 1–28 d, averaging 10.5 d. Males spent 7 d to 2 months in the spawning reach, averaging 30 d. After spawning, 63% of the females moved immediately to Kootenay Lake; the remainder spent a longer time in the river downstream of the spawning reach. Some (52%) males remained in the river, and the remainder migrated to Kootenay Lake. Female behavior and migration was more attuned to environmental conditions than was male behavior. Several environmental variables were examined to determine their effect on female white sturgeon migration to the spawning reach. Changes in temperature and river stage were the best predictors of the probability that females would migrate to the spawning reach. A logistic regression model, when applied to a subset of our original observations, correctly predicted movement to the spawning area 93% of the time. Our model can be used as a tool for risk assessment of white sturgeon spawning migration during various snow pack or temperature forecasts. It will be helpful in determining approximate migration or spawning times, making water management decisions, and assessing effects of temperature fluctuations. The model will be useful to continued study of white sturgeon by predicting spawning migration and improving efficiency in deploying sampling gear.

The Kootenai River had a history of flooding in the lower reach between Bonners Ferry, Idaho (river kilometer [rkm] 246), and Creston, British Columbia (rkm 120; Figure 1). To alleviate flooding, the river was channelized and dykes were constructed to control the flow of water (Redwing Naturalists 1996). In 1972 the U.S. Army Corps of Engineers (USACE) completed construction of Libby Dam, creating Lake Koocanusa. Libby Dam was designed to capture spring runoff from the Canadian Rockies, which left only the local inflow from the watershed below the dam for the spawning of white sturgeon *Acipenser transmontanus*. Soon after the closing of Libby Dam and the filling of Lake Koocanusa, juvenile white sturgeon became very rare in the population (Partridge 1983; Apperson and Wakkinen 1992). Of 185 sturgeon examined between 1977 and 1980, 79% were 15–27 years old (Partridge 1983). Thus, these older fish originated from the years 1951 to 1965 (years prior to Libby Dam), and most of the remaining cohorts preceded this period. The only successful year-classes after construction of Libby Dam were apparently produced in 1974 and 1991, years of exceptionally high water (Partridge 1983; Paragamian et al. 1996). The precise effect of Libby Dam on recruitment of Kootenai River white sturgeon is not known, but inadequate flows during migration and spawning are thought to be an important factor (Partridge 1983). Historical Kootenai River flows ranged 1,416–2,832 m^3/s during the sturgeon spawning period, but after the USACE controlled the spring runoff with Libby Dam, peak flows ranged 250–450 m^3/s or occasionally higher.

When Kootenai River white sturgeon became a state, provincial, and tribal (Kootenai Indian Tribe of Idaho) management and recovery priority, the USACE in 1991–1994 released some water during the white sturgeon spawning period to aid recruitment (Paragamian et al. 1997). However, even these enhanced flows were thought to be far inadequate for white sturgeon spawning and rearing. Because of their mature age structure, continued poor recruitment, and unique genetic distinction (Setter and Brannon 1990), the white sturgeon of the Kootenai River was designated an endangered

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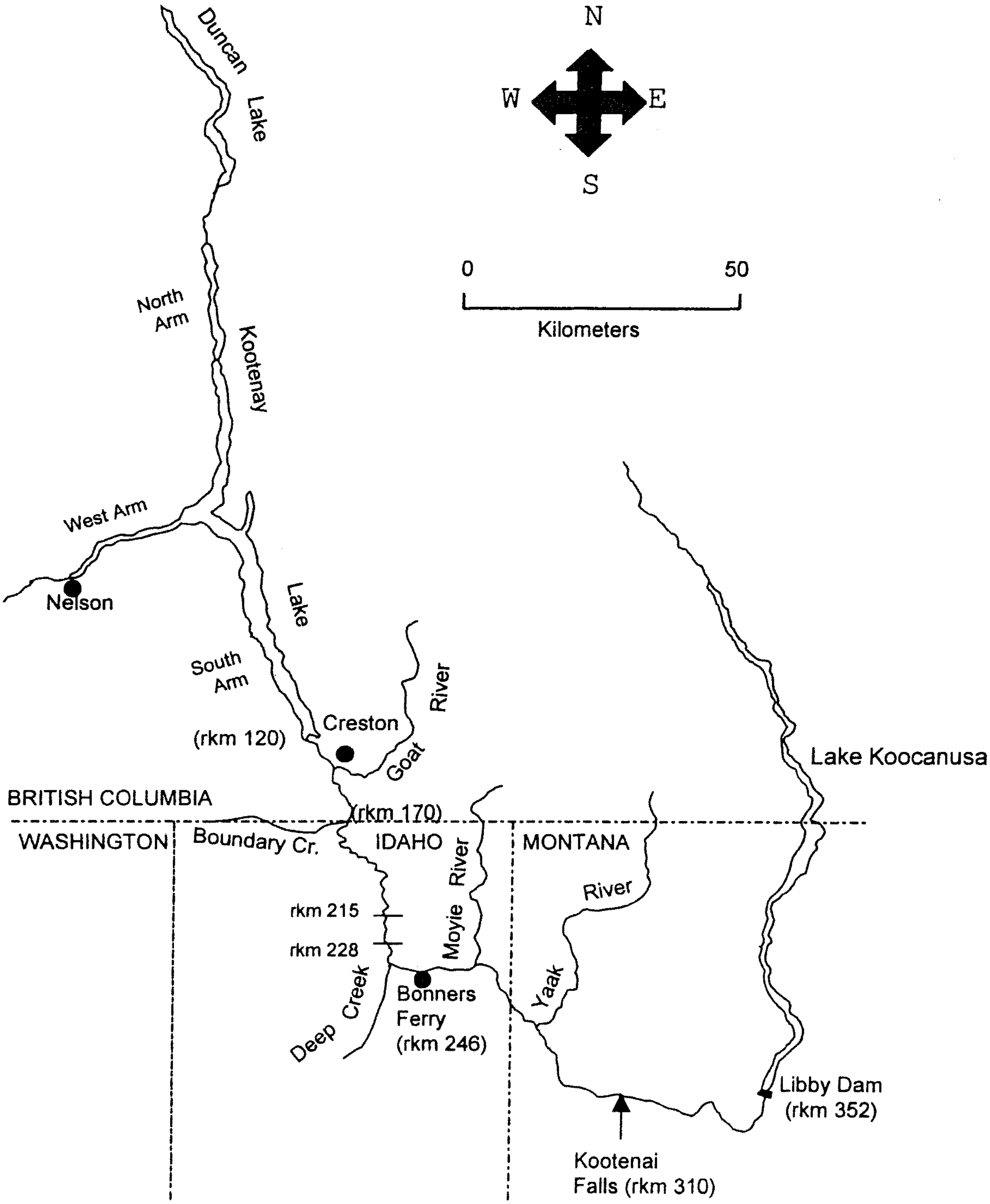

FIGURE 1.—Geographic reference points related to our spawning migration study of Kootenai River white sturgeon. The river distances (in river kilometers, rkm) indicated are from the northernmost reach of Kootenay Lake.

species in 1994. A Kootenai River White Sturgeon Recovery Team (KRWSRT), an international multiagency team, was formed to craft and help implement a recovery plan. The listing action and a recovery plan directed the USACE to provide additional flow for white sturgeon spawning starting in 1995.

Historically, prespawning Kootenai River white sturgeon have migrated during autumn (a few fish move in spring) from the lower river and Kootenay

Lake, British Columbia, to several staging reaches in Idaho between rkm 203 and rkm 216.5. Then in spring they move further to the spawning reach near Bonners Ferry, Idaho (rkm 228–247). However, after the Libby Dam was constructed, we believe that natural migration pattern and spawning behavior, during most years, was disrupted by reduced spring flows. In addition, the environmental variables triggering white sturgeon migration from the staging reaches to the spawning reach were not well identified. Nor did we fully understand how to manage environmental variables to affect behavior patterns of white sturgeon and effect their recovery. The objective of this investigation was to examine white sturgeon migration behavior from 1991 to 1997 and to determine how fluctuations in flow, river stage, temperature, and degree-days influenced behavior. The goal of this research was to develop a model that would predict the probability of white sturgeon spawning migration in response to changes in natural and regulated flows and temperature and thereby help the KRWSRT provide the most receptive conditions for white sturgeon migration, spawning, and eventual recovery.

Methods

River environment.—White sturgeon behavior was studied from the Kootenai River's confluence with Kootenay Lake at rkm 120 to Bonners Ferry, rkm 246 (Figure 1). Bottom substrate in this reach of river is primarily sand, although further upstream it is gravel–cobble.

Estimated flow at Bonners Ferry was calculated from gauging station readings at several major tributaries (below Libby Dam) and at Libby Dam (Pat McGrane, USACE, personal communication). River stages were measured by the USACE at Bonners Ferry and expressed as meters above a base of 518.2 m.

From 1991 through 1994, flow in the Kootenai River at Bonners Ferry, during white sturgeon migration and spawning, was composed primarily of unregulated flows originating below Libby Dam (local inflow). Some additional flow from Lake Koocanusa was added from 1991 through 1994 to enhance spawning. After 1994 the Bonneville Power Administration (BPA) and USACE received a flow design from the U.S. Fish and Wildlife Service (USFWS) in a Biological Opinion Report. This flow design was to provide improved spawning and rearing conditions.

Water temperatures from 1991 through 1997 were recorded at the U.S. Geological Survey (USGS) gauging station at the U.S. Highway 95 bridge in Bonners Ferry. Degree-days (the sum of each average daily temperature above 0°C) were computed for March 1 through July 1, 1994–1997. Temperature data for March and April of 1991–1993 were incomplete.

Adult white sturgeon were captured with rod and reel or set lines from March through April 1991–1997. Rod-and-reel gear consisted of 6/0 hooks and 34-kg-test line. Set lines consisted of a 23-m bottom line equipped with six hooks (two each of 12/0, 14/0, and 16/0) and baited with rainbow smelt *Osmerus mordax*. Most white sturgeon caught from February through March each year were primarily adults in a prespawn condition.

Captured white sturgeon were placed into a hooded stretcher and covered with water during data collection. Fork length (FL), total length (TL) and weight (kg) were recorded for each sturgeon. Most fish greater than 130 cm TL were biopsied to determine gender and stage of sexual maturity (Conte et al. 1988). Biopsies were found to pose no threat to the well-being of white sturgeon (Apperson and Wakkinen 1993). Suspected spawners for the upcoming season were fitted with 50-month radio and 60-month ultrasonic transmitters attached through the base of the dorsal fin. All transmitters were attached with 1.4-mm-thick wire through the proximal portion of the dorsal fin and crimped on.

White sturgeon telemetry.—Adult white sturgeon movements and behavior were monitored throughout the Kootenai River from rkm 120 to rkm 247 and in Kootenay Lake. The main objective was to monitor late vitellogenic females and males moving upstream from staging areas to the spawning reach. Locations of fish were recorded to the nearest 0.1 rkm. Telemetry from 1991 to 1993 was concentrated in the spawning reach (rkm 228–247) several days a week after fish had moved from staging areas, but only weekly outside of the spawning reach. However, effort was nearly daily within the staging and spawning reaches from April through July of 1994–1997. These latter years provided us with a log of daily movements of fish. We also used receivers at two fixed locations (rkm 238 and rkm 245) from 1995 to 1997 to monitor white sturgeon movement 24 h/d, as well as aerial tracking from a fixed-wing aircraft. Receivers at the fixed locations provided supplemental data and recorded nighttime movements and movements to the reach of river near Bonners Ferry. Verification of spawning was achieved during a companion study.

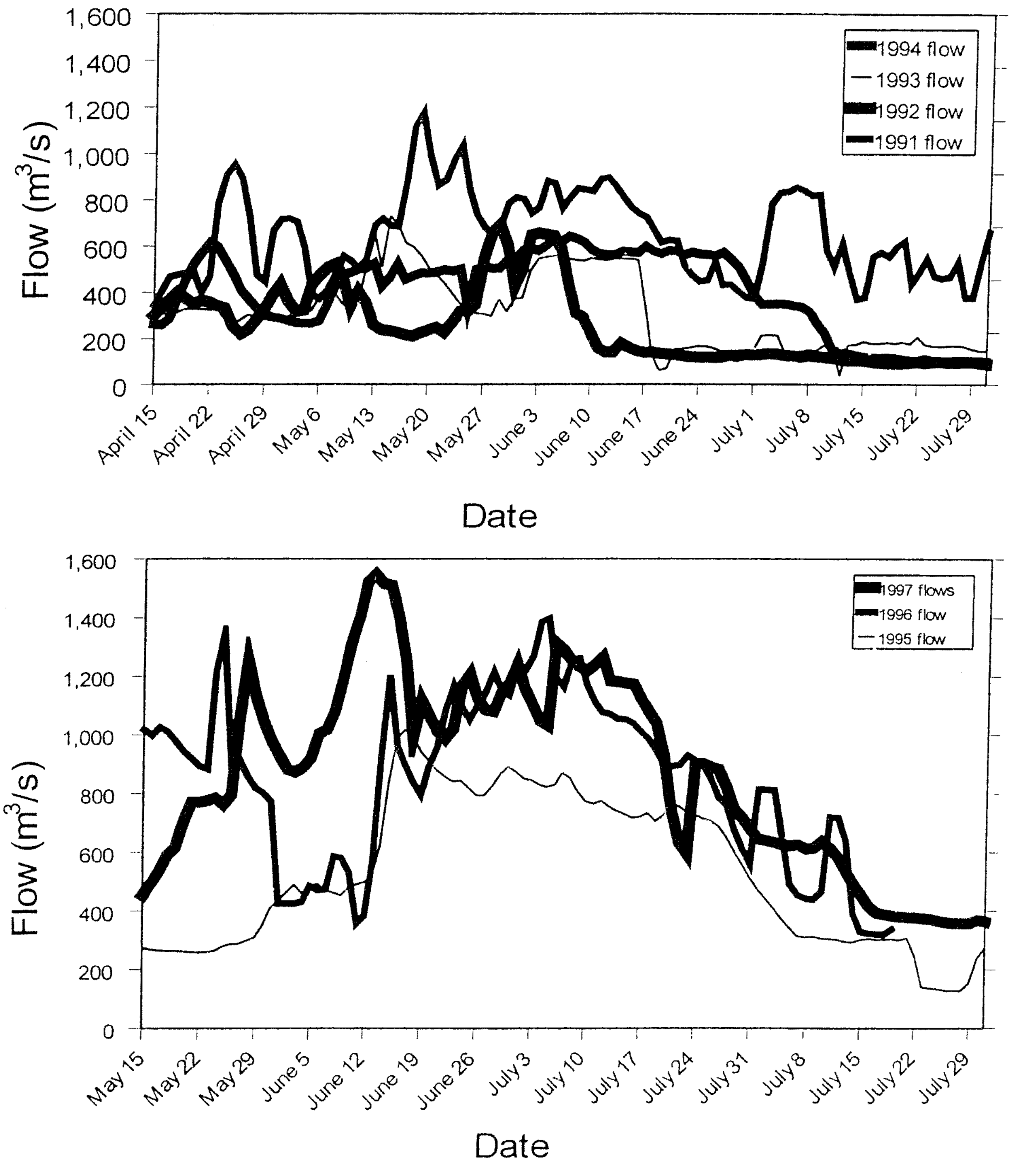

FIGURE 2.—Daily flow (m^3/s) in the Kootenai River at Bonners Ferry, Idaho, from April 15 through July 30 for 1991–1994 (upper panel) and for 1995–1997 (lower panel). Flows in 1992 and 1993 were calculated from above Bonners Ferry.

Data analysis.—Statistical analyses of white sturgeon movements and environmental variables were carried out separately for each sex. Regression analysis was used to identify any relationship between length of white sturgeon and the day of migration and the length of time spent in the spawning reach. Analysis of variance (ANOVA) was used to determine differences between sexes in the length of time spent in the spawning reach. White sturgeon movement patterns and responses to the various environmental variables in the prespawning period and during the spawning migration were also examined. Stepwise discriminant analysis was used to determine which combination of two environmental factors would best predict white sturgeon spawning migration. Logistic regression analysis was then applied, incorporating the results of the discriminant analysis, to provide a model to predict the probability of white sturgeon migration under different combinations of the two variables.

Results

River Conditions 1991–1994

Flows at Bonners Ferry during Kootenai River white sturgeon migration and spawning varied annually before and after Endangered Species Act (ESA) listing of sturgeon, depending on flood water control, precipitation, local inflow, and flow mitigation (Figure 2). Flows in 1991 were influenced primarily by local inflow, which combined with discharge from Libby Dam, raised it to a peak of 1,190 m^3/s in mid-May. Flows at Bonners Ferry in 1992 were the lowest during this study. Local inflow subsided in early May 1992, and discharge from Libby Dam was reduced to about 200 m^3/s for about 2 weeks. A request from the Idaho Department of Fish and Game to increase flow for white sturgeon spawning mitigation resulted in an increase from late May through early June (about 14 d) that reached 736 m^3/s. A minimum augmented flow for white sturgeon spawning provided June 1, 1993, brought flows to 583 m^3/s on June 6; the augmented flow ended on June 16 (Figure 2). In 1994, local inflow from below Libby Dam brought flows to a peak of 615 m^3/s in April, preceding the white sturgeon spawning flow augmentation from late May through early June.

April 15–July 1 temperature means from available 1991–1994 data were about 9.6, 11.8, 11.0, and 10.6°C, respectively (Figure 3). The warmest season during this study was 1992, when water temperature increased from about 6°C in mid-April to 21°C by the end of July and averaged 11.9°C.

River Conditions 1995–1997

Listing of Kootenai River white sturgeon in 1994 under the ESA resulted in increased flows for white sturgeon spawning during the following years (Figure 2). Flow in 1995 peaked with local runoff in mid-June at just over 1,000 m^3/s and soon afterward, with augmented flow, was maintained at greater than 700 m^3/s through June 30. Near-flood conditions from local runoff prevailed in 1996. Flows during 1996 peaked at 1,396 m^3/s and exceeded 800 m^3/s from mid-June through mid-July. Peaking at 1,547 m^3/s on June 12, flow rose again after the spawning season to about 1,400 m^3/s in early July. Flows in 1997 exceeded those of all study years and exceeded 1,000 m^3/s from mid-June through mid-July. Most of this water was from local inflow, whereas the water from Libby Dam was passed primarily to protect against overfilling Lake Koocanusa. The highest annual gauge heights during this study ranged from 16.2 m (1993) to 19.6 m (1997).

Temperatures at Bonners Ferry were affected by thermal warming and by the volume and location of water withdrawals from Libby Dam. Temperature means from 1995 through 1997 were 8.0, 7.8, and 8.1°C, respectively, from April 15 through July 1.

Location of water withdrawal from Lake Koocanusa was changed on several occasions to add warmer water to enhance sturgeon spawning (e.g., 1995 and 1997). Water was coolest in 1996, starting at about 5°C in mid-April and reaching 12°C by the end of June. Degree-day records (1994–1997) indicated 1994 was the year of most rapid warming, reaching a total of 1,045°C units by July 1, whereas 1995 was second with 830°C units by July 1 (Table 1). The coolest year was 1997, with 778°C units by July 1.

White Sturgeon Sampling

We attached sonic or radio tags or both to 28 male white sturgeon and 27 females from 1991 through 1997 (Table 2). Five males were repeat spawners and were monitored for two or more spawning seasons from 1991 to 1997 (four males were monitored during two spawning seasons and one was monitored during three spawning seasons). The 22 male white sturgeon ranged from 122 to 219 cm TL (FL = 105–200 cm) and weighed 23–76 kg. The 27 females were 164–258 cm TL (FL = 145–212 cm) and weighed 26–98 kg. Three white sturgeon (males) were tagged in the spawning reach (rkm 228–230), three were tagged in Kootenay Lake (as far as rkm 20), and the remainder were tagged at one of three prespawn staging areas (rkm 203–206, rkm 207–208, and rkm 215–216.5). Popular staging reaches were characterized by deep (up to 20 m) broad reaches with sand substrate and slow water velocities (<1 m/s).

Telemetry

We monitored the movements of 2–14 mature white sturgeon each year (Table 2) and recorded 2,805 telemetry contacts. Before spawning migra-

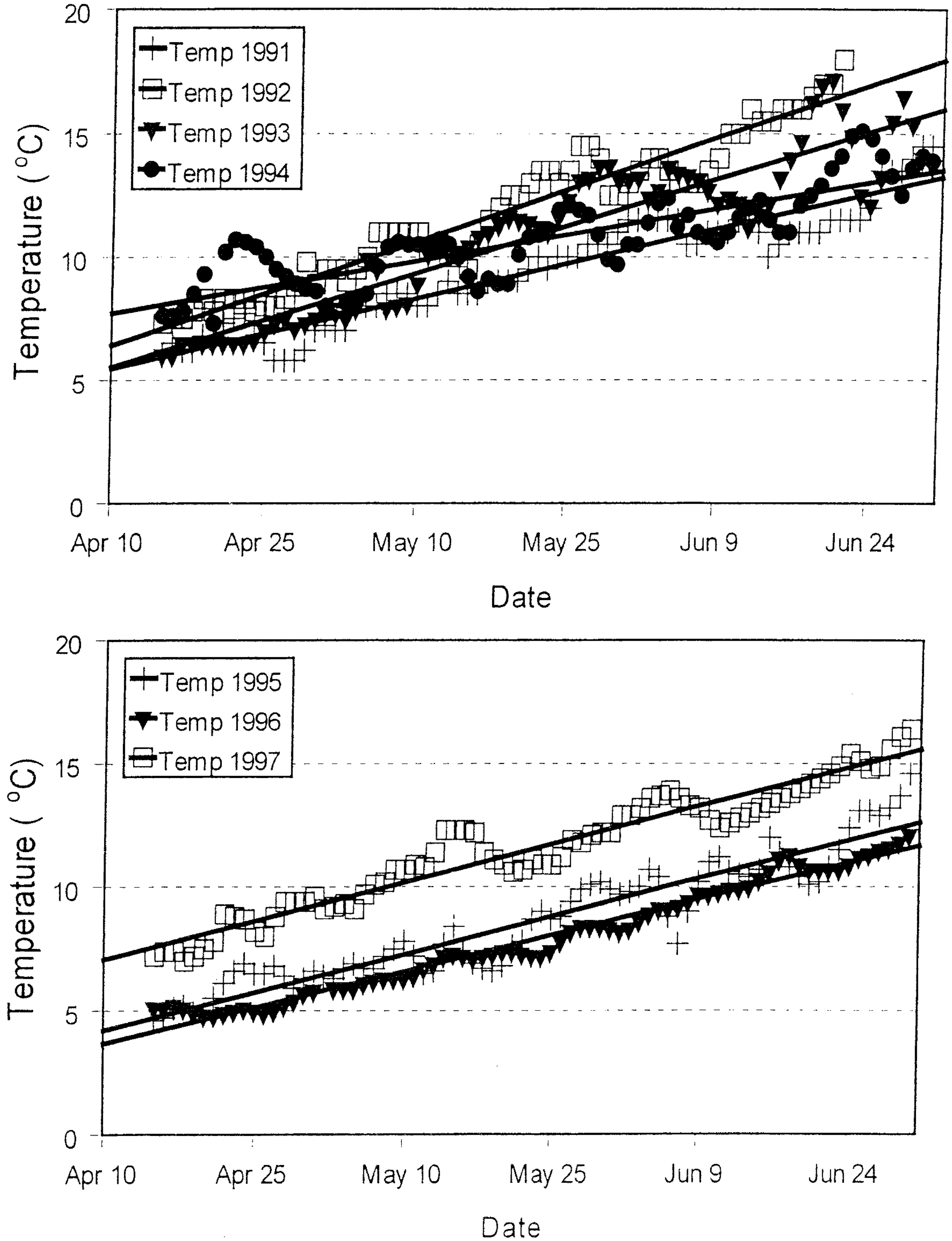

FIGURE 3.—Daily temperatures for April 15–July 1 and their regressions for the Kootenai River at Bonners Ferry, Idaho, for 1991–1994 (available data; upper panel) and 1995–1997 (lower panel).

tions began, male and female white sturgeon demonstrated frequent short-range daily movements in the vicinity of respective staging reaches. Most movements ranged 0.1–1.0 km, but some fish moved extensive distances. For example, one male moved about 10.0 km/d in and out of the same staging reach.

White sturgeon males were usually the first to

TABLE 1.—Degree-days (°C), selected dates, 1994–1997, for the Kootenai River at Bonners Ferry, Idaho.

	Degree-days			
Year	Apr 1	May 1	Jun 1	Jul 1
1994	146	354	668	1,045
1995	163	350	493	830
1996	103	261	481	793
1997	104	217	444	778

TABLE 2.—Spawn year (year in which spawning was believed to have occurred) and sex of white sturgeon monitored in the Kootenai River spawning reach by radio and sonic telemetry, 1991–1997. Number tagged are the number of tagged fish believed to have spawned; five males are thought to have spawned in one or more years.

Spawn year	Sex	Number tagged
1991	♂	2
	♀	0
1992	♂	0
	♀	5
1993	♂	4
	♀	4
1994	♂	4
	♀	2
1995	♂	7
	♀	7
1996	♂	5
	♀	6
1997	♂	6
	♀	3

migrate from staging areas (rkm 203–216.5) to the spawning reach (rkm 228–247). On average, male sturgeon began their spawning migration 6.8 d after the onset of rising local runoff. Each year, most male white sturgeon arrived about 2 weeks before the first evidence of spawning.

Migrations of male and female white sturgeon were also frequently associated with rising water temperature and rising flow. Temperatures on the first day of recorded male spawning migrations varied each year, ranging from 5.5°C to 12.1°C. Males spent significantly longer periods (P = 0.0001) in the spawning reach (7 d to several months, average 30 d); 84% stayed 13–48 d (Figure 4). About 52% of the males remained in the river (rkm 120–230) after spawning; the others returned to Kootenay Lake (spawning of white sturgeon was verified each year with the collection of eggs in a companion study).

Female white sturgeon usually migrated to the spawning reach several days to a week after the males but some females moved sooner. Females started their spawning migration an average of 15.3 d after the beginning of a rise in local runoff. Migration of females was also associated with rising temperatures. Spawning (recorded in a companion study) began 1 d to nearly 2 weeks after the arrival of the first female with a transmitter. Temperatures on the dates that females began migration varied each year, ranging from 6.6°C to 10.7°C. Females remained within the spawning reach from 1 to 28 d, averaging 10.5 d (Figure 4). Although 37% spent 3 d or less at the spawning reach, 56% were present 4–21 d, and only 7% for 22 d or more. After spawning, 63% of the females returned to Kootenay Lake.

Spawning Reach Abandonment

In 1992 five female white sturgeon with transmitters began upstream migrations while local inflow of the Kootenai River was rising. However, when local inflow began to subside after peaking, the river water level began falling rapidly, creating a low-flow period. Females arrived at the spawning reach during a discharge of about 243 m^3/s. All five tagged females apparently abandoned the spawning reach soon after arrival, as we were unable to relocate them after the first day of our record. A month later they were located in Kootenay Lake. Within 2 weeks, flows were elevated to 736 m^3/s, but females did not return.

Flows in the second half of May 1993 declined from about 700 to 300 m^3/s (Figure 2). During this period two of four females and two of four male sturgeon abandoned the spawning reach. Flows were increased in late May and by early June were stabilized for 2 weeks at about 535–583 m^3/s. The males returned to the spawning reach but the females did not. We did not observe this behavior in 1991 or from 1994 through 1997, when flows at Bonners Ferry were augmented during the spawning season. Spawning reach abandonment biased our estimates of the average length of time females stayed in the spawning reach.

Statistical Analysis of Data

We could not detect a statistical relation (α = 0.05) between the size of male sturgeon and the timing of migration or the length of time spent in the spawning reach. Nor did we detect a statistical relation between the size of females and the timing of migration or the length of time spent in the spawning reach.

Only 1994–1997 data were used for development of our model because each telemetry record had to be complemented with complete environmental measures. Statistical comparisons of the

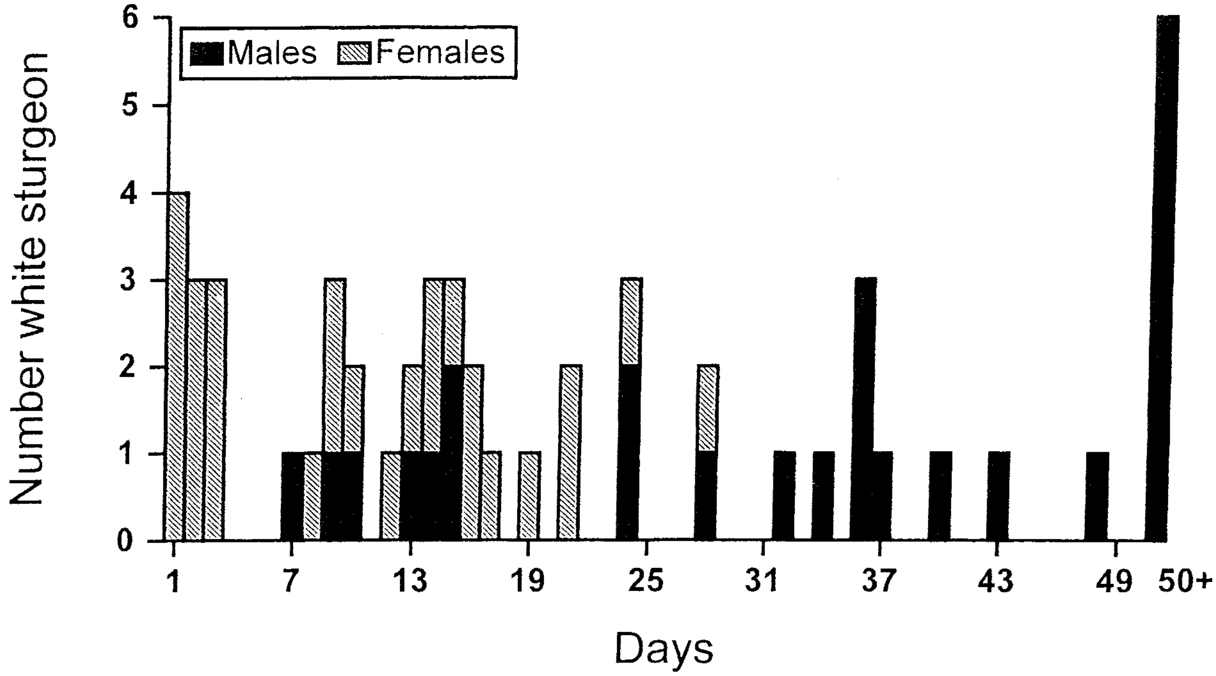

FIGURE 4.—Number of days that individual male and female white sturgeon spent in the Kootenai River spawning reach, 1991–1997. Three males that were captured and tagged in the spawning reach are not included.

movement and behavior of males and environmental variables were all insignificant ($P > 0.05$), indicating there were no clear behavior patterns linked to environmental conditions. Therefore, in this study we present only the statistical findings for female white sturgeon, which did show significant relations between movement and behavior and environmental variables. Our 1994–1997 telemetry sample of 17 females included 1,342 records during the staging period (an average of 79 contacts/fish) and 107 records (an average of 6 contacts/fish) during the migration from staging areas to the spawning reach. For each period we calculated the means and standard deviations of environmental variables (Table 3).

Stepwise discriminant analysis was used to identify the two best variables for a predictive model. Analysis indicated that temperature was the most important factor to the onset of female white sturgeon migration and that river stage was the second most important variable ($F = 212$, 2; df = 1,446; $P \leq 0.001$). Combined, the model for migration is

$$M = -74.48 - 0.4(T) + 8.66(\mathrm{RS}),$$

where T = temperature and RS = river stage.

A logistic regression model to predict sturgeon migration was developed. First a random sample of about 25% of the original 1994–1997 observations ($N = 376$) of staging and migration, temperature, and river stage were set aside as the "validate" set. A logistic regression validation model was then developed from the remaining observations ($\chi^2 = 379.571$, df = 2, $P = 0.0001$). We then predicted the validate set and compared the percent correct to the remainder used to develop the model. We found that the model correctly predicted 93.4% of the validate set. A logistic regression model was then developed using all sturgeon observations and temperature and river stage to predict the probability that female white sturgeon would respond to an alteration in either or both by migrating from a staging area to the spawning reach (Table 4); the probability of female sturgeon migration is

$$P_{\mathrm{migration}} = e^u/(1 + e^u),$$

where $u = -19.769 + 1.228\,(T) + 0.550\,(\mathrm{RS})$.

TABLE 3.—Means (SDs) for environmental variables during Kootenai River female white sturgeon staging and spawning migrations from March 1 to July 1, 1994–1997.

Variable	Staging period	Migration period
Temperature (°C)	4.75 (1.80)	8.05 (0.98)
Degree-days (°C)	1,327 (1,099)	3,342 (1,286)
Flow (m^3/s)	492 (310)	933 (260)
River stage (m)	15.144 (1.45)	17.421 (1.27)

TABLE 4.—Temperature and river stage logistic regression statistics for the spawning migration of Kootenai River female white sturgeon, March 1 to July 1, 1994–1997.

Effect	Estimate	SE	*t*-ratio	*P*
Constant	−19.769	1.732	−11.413	0.000
Temperature (°C)	1.228	0.116	10.611	0.000
River stage	0.550	0.089	6.160	0.000

This logistic regression model correctly predicted female white sturgeon movement to spawning areas 92% of the time when applied retrospectively to our original observations. We prepared a figure, based on river temperature and stage, from which to estimate migration probability at the 5, 25, 50, 75, 85, and 95% probability level (Figure 5).

Discussion

Female white sturgeon in the Kootenai River demonstrated more consistent behavior, appeared to be more sensitive to environmental conditions, and were more useful in predicting the probability of migrating to the spawning reach than did males. Females migrated to the spawning reach within the narrowest time frame and left the spawning reach soon after spawning; they also appeared to be the most likely to abandon the spawning reach after rapid decreases in flow. In contrast, males were unpredictable in their migration to and from the spawning reach, were more tolerant of environmental changes, and frequently spent many weeks within the reach after spawning had ceased. These behavioral differences could bias population estimates, estimates of sex ratios, and estimates of proportions of adults in various stages of maturity. This bias could be reduced by systematically sampling the entire river and lake for adults. Differences in behavior between sexes may also be present in other white sturgeon populations, and these differences should be considered in studies similar to ours.

Spawning reach abandonment by Kootenai River white sturgeon, because of inadequate flows, may have been a common phenomenon and could have led to poor or failed spawning and recruitment following Libby Dam construction. During our study, females abandoned their spawning reach when flows were allowed to decrease rapidly in 1992 and 1993. During both years sturgeon had migrated to the spawning reach when local inflow was greater than flows from Libby Dam, which were only 113 m^3/s (base flow). When local inflow subsided and flows at Bonners Ferry became less than 50% of the previous peak, none of the five females tagged in 1992 could be relocated in the spawning reach. In 1993 two males and two females left the spawning reach under the same condition of descending flows. In both years the discharge from Libby Dam was eventually augmented to improve spawning conditions, but none of the females returned; the two males in 1993, however, did return. Prior to the recovery actions, flows in the Kootenai River averaged about 500 m^3/s in May (primarily water from local inflow) but subsided in June (Figure 2). The USACE could also power peak, raising or lowering flows for power. In the Kootenai River most spawning takes place in June. No eggs were recovered in 1992 and only two in 1993 (Apperson and Wakkinen 1992, 1993). In addition, one female white sturgeon recaptured in the autumn of 1992 was resorbing its eggs (Apperson and Wakkinen 1993). Similar results occurred in 1999 (Paragamian et al. 1999). These findings support the concept that flow augmentation for spawning should be based on white sturgeon behavior, specifically their migration timing to the spawning reach, rather than on a calendar date (as in 1992 and 1993).

An objective of the Kootenai River White Sturgeon Recovery Plan is to restore some of the natural spring hydrograph for wild spawning and rearing of white sturgeon. Kootenai River white sturgeon responded to artificial flow measures from 1994 through 1999 by migrating substantial distances and then spawning (Paragamian et al. 1998, 1999). Although there has been some success at measuring recruitment of young white sturgeon from the years of mitigated flow, the present level of recovery is unknown (Paragamian et al. 1997). Other investigators have documented that high spring river flows are important to recruitment to white sturgeon as well as other sturgeon species (Alekperov 1966; Shubina 1971; Khoroshko 1972; Votinov and Kas'yanov 1978; Parsley 1991; Parsley and Beckman 1994; Auer 1996; Nilo et al. 1997).

After a substantial portion of the Kootenai River spring flow was restored, temperature was an important variable in predicting female white sturgeon migration. Male sturgeon in the Kootenai River migrated at lower temperatures than did females. Prespawn male Gulf sturgeon *A. oxyrinchus desotoi* in the Choctawhatchee River of Florida and Alabama were also found to migrate at cooler temperatures (Fox et al. 2000). In the Snake River flows appeared to be important to migration of

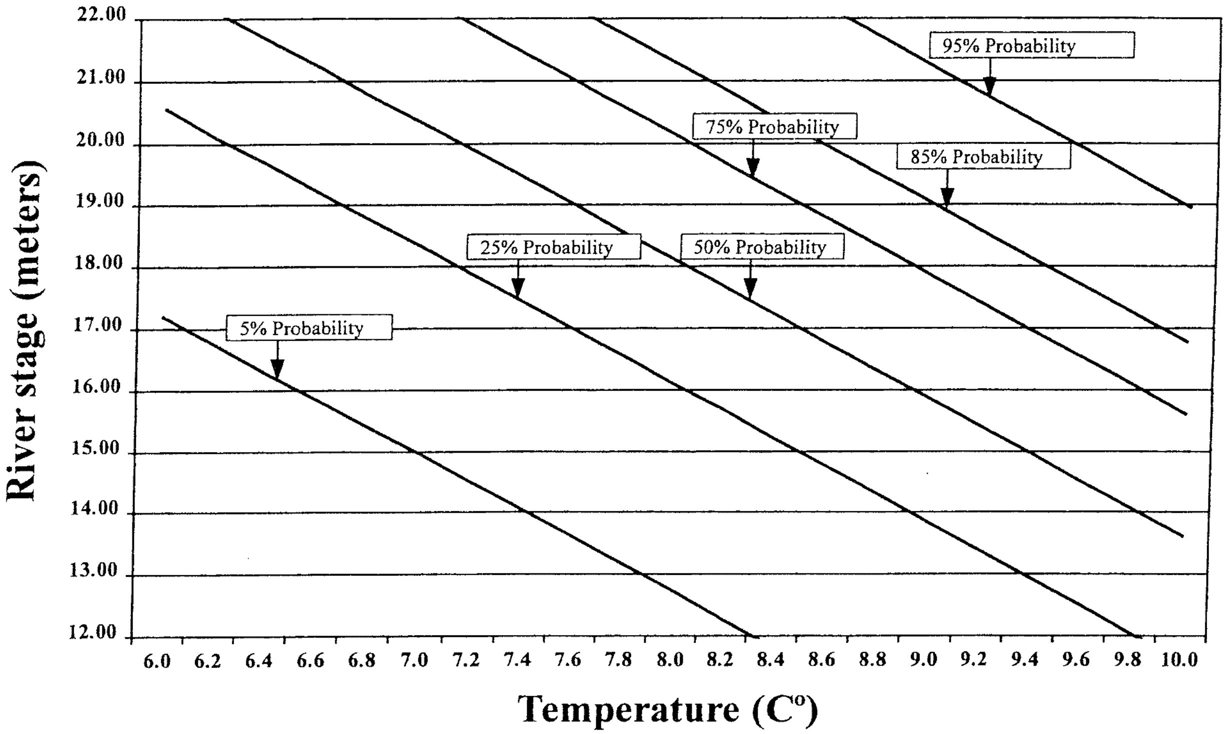

FIGURE 5.—Probabilities (5, 25, 50, 75, 85, and 95% levels) that female white sturgeon would migrate from a staging reach to the spawning reach of the Kootenai River, based on river temperature and river stage.

both sexes of white sturgeon (Coon 1977) but not as important as temperature in the Hanford reach of the Columbia River (Haynes et al. 1978; McCabe and Beckman 1990).

We combined temperature and river stage in a logistic regression model to devise a management tool that would predict the probability of female sturgeon beginning their spawning migration. For example, to initiate female white sturgeon spawning migration when the ambient river temperature is 6°C, river stage is 16.8 m, and reservoir mid-surface temperature is 10°C, we predicted an 85% probability that females would migrate if mitigated flows increased the water temperature at Bonners Ferry to 9.6°C and the river stage to 18.0 m. We used our model and graph to predict the migration probability for seven females monitored in 1998; their individual probabilities on the date of migration were 65, 75, 75, 79, 83, 85, and 89% (Paragamian et al. 1998). Our model will also help the KRWSRT in the decision making process and promote understanding of the association of temperature, flows, and river stage. It will provide the team with a tool for assessing risks to spawning migration during years of various snow pack or temperature forecasts. The model will be helpful in determining approximate migration or spawning time, water management decisions, and the effects of temperature fluctuations. The model will be useful to our continued study of Kootenai River white sturgeon by more efficiently predicting timing of spawning migration and spawning and will enhance efficiency in deploying sampling gear. The model will also be helpful to predicting sturgeon behavior in the event that handling and monitoring of adults becomes more restrictive.

We do not expect our model to fit white sturgeon populations in the Columbia Basin because Kootenai River white sturgeon are active at lower temperatures; however, a similar relationship may exist. Kootenai River white sturgeon began spawning migrations at temperatures as low as 5.5°C and spawned at 8–10°C. Haynes et al. (1978) found that spring movements of white sturgeon in the Hanford reach of the Columbia River began at 13°C. Beamesderfer et al. (1995) found that catch rates for white sturgeon increased in the Dalles and Bonneville reaches of the Columbia River when temperatures rose above 10°C. Telemetry data from mature adult white sturgeon tagged in the Columbia River below Castlegar, British Columbia, between 1990 and 1992 suggested they did not migrate to the spawning reach until temperature approached 14°C (RL&L Environmental Services 1997).

Other factors associated with migration timing and spawning of white sturgeon not addressed in our study include, for example, physiological factors influencing the maturity and reproductive readiness of sturgeon (Conte et al. 1988). Also, males and females mature at different rates and spawn over different intervals (Chapman 1989; Beamesderfer et al. 1995; Devore et al. 1995), males spawning about every 1–3 years and females every 5–7 years.

White sturgeon throughout the Pacific Northwest and other sturgeon species throughout the world are at risk of extinction (Birstein 1993) because of fragmentation of populations, overexploitation, and loss of spawning habitats due to hydro and flood control dams. Beamesderfer and Farr (1997) stated that "life history traits that have proven adaptive over the last 100 million years are now a disadvantage in the face of drastic habitat changes and overfishing during the last century." Researchers and managers must continue efforts to restore rivers to normal flow and temperature regimes for the recovery and preservation of white sturgeon.

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